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mathematicus umbraticola

Lt. Col. Charles K. Reed, Assistant Executive Director, AFOSR

Karl Pohlhausen, an internationally renowned electrical and aeronautical engineer and one of the most distinguished civilian scientists on the technical staff of the Office of Aerospace Research, retired on 30 May 1962 from his position as Senior Applied Mathematician in the Applied Mathematics Branch of the Aeronautical Research Laboratories.

At a dinner on 17 May, his professional colleagues presented to Dr. Pohlhausen an anniversary volume of original research papers in commemoration of his seventieth birthday.

The introduction to the volume was written by Theodore von Karman, and this dedication was an appreciation and remembrance of the Karman-Pohlhausen association and the origins of their celebrated collaboration on the theory of the boundary layer.

The technical papers contributed to the book were:

"A Note on Plane Sound Waves of Finite Amplitude" by Knox Millsaps

"Numerical Evaluation of Continued Fractions" by Gertrude Blanch

"Factorization, Partitioning of Systems of Ordinary Differential Equations and Two-Point Boundary Value Problems" by Karl Gottfried Guderley

"Satellites and Riemannian Geometry" by Herbert Knothe

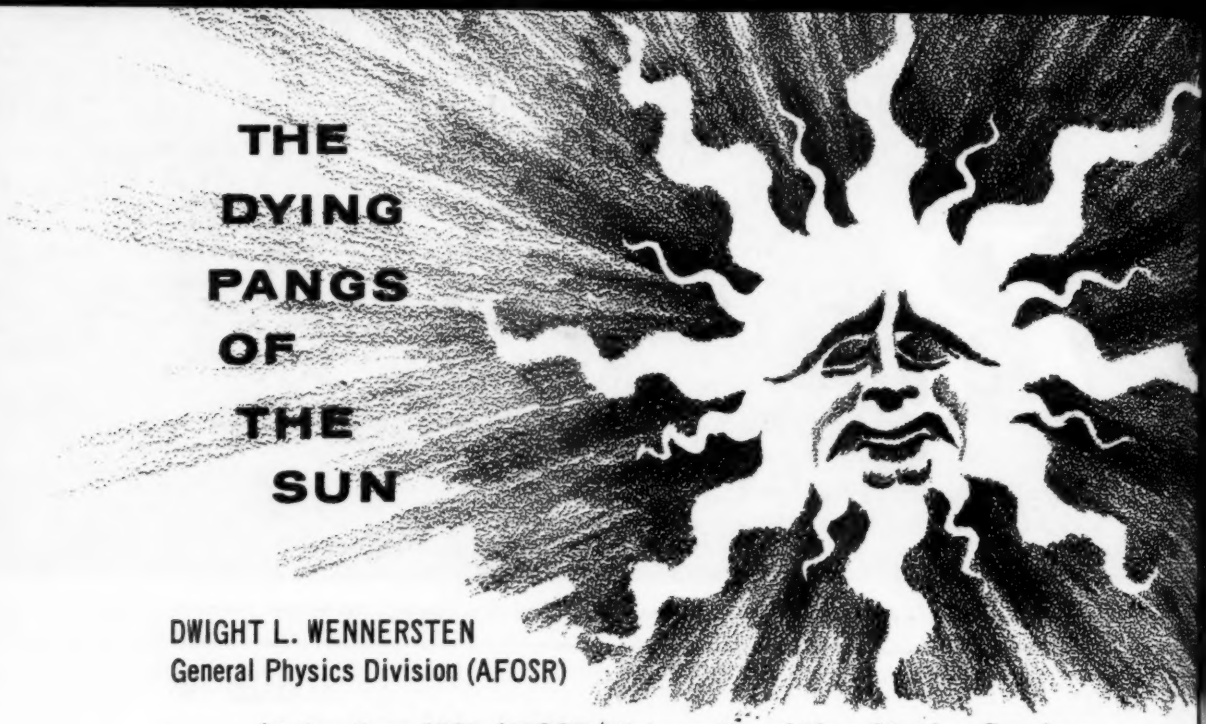
"A New Solution for the One-Dimensional Steady Shock Wave in Heat Conducting Viscous Gases" by Bruno J. Manz

"Analysis and Experiment for Free Convection Boundary Layers with Non-Similarity Thermal Boundary Conditions" by E. M. Sparrow

"Numerical Penetration Depth in Solid Round Conductors" by A. S. Timascheff

Copies of the work may be obtained by writing to the Assistant for Technical Publications in the Directorate of Research Analyses of the Air Force Office of Scientific Research at Holloman Air Force Base, New Mexico.

THE DYING PANGS OF THE SUN



DWIGHT L. WENNERSTEN
General Physics Division (AFOSR)

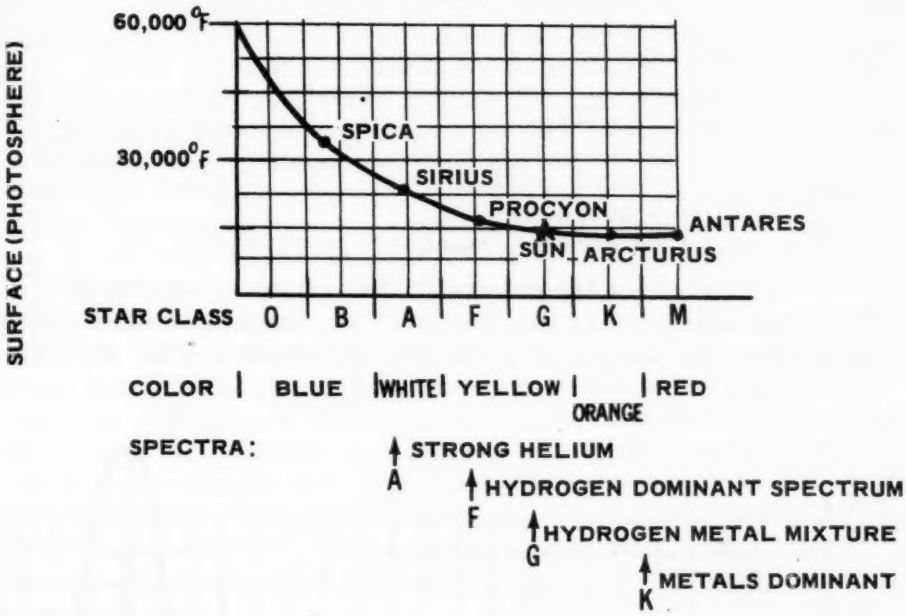
At the June 1962 AFOSR/University of New Mexico Seminar on "Topics in Geophysics," Dr. Allan Sandage of the Cal Tech -- Mount Wilson -- Mount Palomar complex stated his conviction that our middle-aged sun would die --- "go out" as far as radiation useful to its planets is concerned. He hastened to add that future generations of the 3rd planet would not have to make provisions for the intense cold, however, for a simple reason. That reason is: a billion-year-long heat flash will precede the black out.

This curious paradox arises from a better understanding that our sun is a very average member of a dynamically evolving class of stars called main-sequence stars. We, speaking for our sun, have lots of company. There are billions of other main-sequence stars in our galaxy, the Milky Way, and more billions exist in each of more billions of galaxies. This statistical averageness has permitted the astrophysicists over the past 50 years to refine their developing theories against abundant real evidence in the nighttime sky. Fortunately the processes involved are simple though the far-away end is a bit discouraging in its inevitability.

H. N. Russell of Princeton set the modern development pace in a 1914 lecture wherein the basic pattern of average stars was shown to fit a smooth curve on a graph which plots absolute brightness (luminosity or temperature - or absolute magnitude) against color or spectral type. This curve is called the H-R diagram as an abbreviation for Hertzsprung-Russel diagram because Russel drew

strongly on data collected by Hertzsprung over the 1905-10 period for stars near enough that their distances could be determined accurately by trigonometric methods using the diameter of the earth's orbit as a base line. The inverse square law then permitted setting true luminosity from the apparent luminosity as observed at the earth. The H-R diagram is sketched in Figure 1.

FIG.1



The "line" is not sharp, but is the average of populations ten or so times the line width, up and down. This variability leads to the logical question, "What equations apply to individual stars that are on or near the main sequence center line shown in Figure 1?"

The equations arise from a theorem called the Vogt-Russel Theorem: "The structure of a star in equilibrium is uniquely determined by the distribution of chemical composition and the total mass, provided the equation of state, the opacity (inverse of transparency) and the energy production are functions only of the local physical variables and the composition." The last half of the theorem, after the first comma, is necessary for completeness and to cover unusual stars or stars in unusual local environments, but for well-behaved stars such as our sun, it could end at the twentieth word by changing the comma to a period. This theorem has been "proven" by

thousands of calculations and spectographic and photometric measurements. The equations arising are as follows:

$$L = f_1(m_1 \mu)$$
$$T = f_2(m_1 \mu)$$

Vogt-Russel Theorem

yielding, by substitution:

$$L = f_3(T, \mu)$$

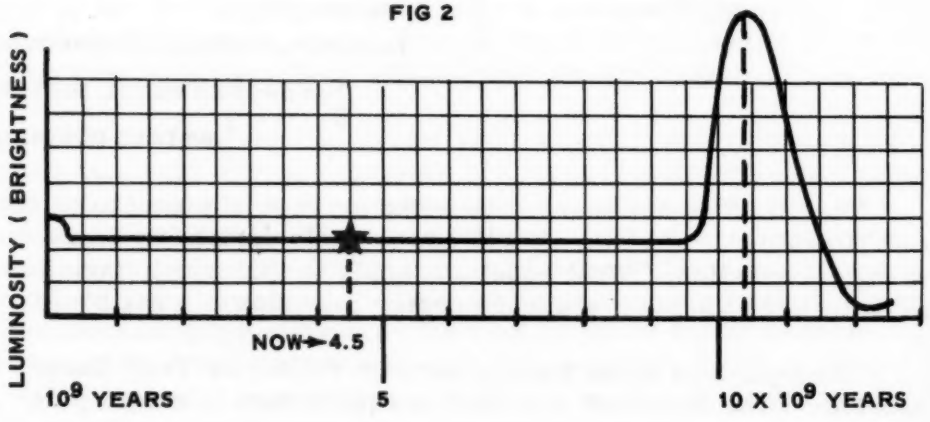
and if u = a constant,

$$L = f_4(T).$$

Here L = luminosity
T = temperature
μ = a constant related to composition.

From detailed studies of the sun and other similar "F" and "G" class stars it was then possible for Sandage to draw a second graph giving the time history of the sun's luminosity. This is Figure 2.

FIG 2



In this graph Sandage spans the life history of a G-type star, our sun, with a composition approximately 90% hydrogen, 10% helium, 1% carbon and heavier non-metals, and 1/4% metals. The sun is judged to have "burned" quietly, more or less, at a fairly constant photospheric temperature of 6000° C for 4 1/2 billion years with 5 billion to go. During this quiet period, about 10% of the original 90% of hydrogen burns to helium by the following chain reaction at about

20 million degrees C:

$H^1(p, \beta) H^2$ $H^2(p, \gamma) He^3$ $He^3(He^3, 2p) He^4$

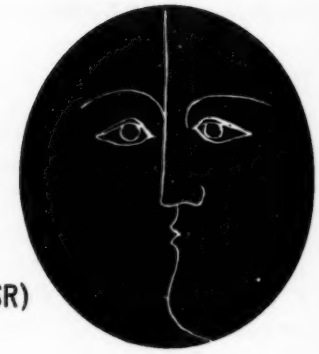
At about the 9.5 billion-year point, the thermal furnace burning hydrogen becomes clogged with helium-four clinkers. The temperature drops slightly with a reduction in outward radiation pressure and gravity collapses the inner core of the sun, causing a delayed increase in temperature near the center of the sun from 20×10^6 degrees C to about 2×10^8 degrees where the helium begins to "burn" with $3He^4$ resulting in C^{12}. This is the heat pulse mentioned earlier and shown on Figure 2. At the start of the helium burning phase, some of the outer material will probably be ejected and the sun, as a whole, will oscillate in size and brightness, settling down then to a dynamic situation where the size and brightness increase steadily (Fig. 2). Correspondingly, the solar radiation constant at the earth will increase from the present two calories per square centimeter per minute which gives the earth an average temperature of 15° C to a higher rate which will raise the temperature over a few hundred million years to about 500° C. During this time events on the earth will go through a quite predictable chain. First the polar caps will melt, raising the oceans 50 feet or so, then the elevated temperature will put more vaporized water into the atmosphere with torrential afternoon and nighttime rains. Then the oceans will recede as more and more water remains vaporized. Finally the oceans will go dry and the exposed rocks then will follow the increase in the sun's brightness more closely as temperatures increase to 500° C. This latter temperature is above the melting point of soft metals such as lead and zinc, so it is unlikely life can survive.

what oceans?

The return trip from 500° C downward is expected to be more rapid and to progress farther with all oceans eventually freezing and then the atmosphere precipitating starting spectacularly with carbon dioxide snow and ending when the lighter gases freeze out. This cycle follows the decay of the sun's temperature to equilibrium with the interstellar space around it, not far above absolute zero.

The foregoing time-story of the earth-sun relationship is not a real challenge to the predictive powers of the scientific theory of the H-R diagram and the associated computer-based astrophysics of stellar interiors and evolution. Future descriptions are planned on the extensions by the Cal Tech group with partial support by the General Physics Division, AFOSR, to planet formation, heavy-element synthesis and the "big-bang" theory of cosmology.

"know then thyself"



ROBERT V. BROWN, Biological Sciences Division (AFOSR)

One of the most perplexing problems in physiology or, for that matter, in human affairs, has been the exact mechanism involved in learning. The older theories have all left much to be desired, as they did not offer any explanation as to the physical changes which made a learned act virtually unforgetable.

Recently, at the University of Goteborg, Dr. Holger Hyden, working under a grant from the AFOSR, has discovered many facts about learning mechanisms. The following facts, both Hyden's and others are known. Neurones produce ribonucleic acid and proteins on a large scale. The production increases with stimulation. External stimulation is necessary for proper neurone development and also for maintenance. In man, the amount of RNA in anterior horn cells increases until age forty, remains constant for some twenty years, then it gradually falls to much lower levels. The glia and nerve cells are closely linked metabolically, down to the Molecular level.

Upon extensive stimulation, such as occurs during conditioning, the RNA in neurones increases to a great extent. The chemical composition of this increased RNA changes significantly.

As a working hypothesis of how learning takes place Dr. Hyden offers the following theory based upon these factors. Genetically, the RNA contains the "inherited properties of the race". This in turn is reflected in the original RNA composition. With stimulation, the glial cells and the neurone together constitute a functional unit. The glia do not change their energy metabolism with continuing stimulation; the neurone greatly increases its metabolism and RNA production.

The new RNA produced is of different chemical constitution from that originally present, showing fairly marked changes in percentages of bases. This change is present throughout the neurones making up the entire nerve path involved. The changed RNA reproduces itself,

thus perpetuating the change. Protein synthesized by this changed RNA is chemically different from earlier protein and is highly specific for all the cells involved.

It is assumed that this specific protein responds to the same stimulation which originally produced the changed and specific RNA. In responding, the specific protein explosively reacts to its proper stimulus, bridging the synapse, either electrically or by a transmitter substance or both. The specific protein "downstream" does likewise, transmitting the effects only through neurones having similar specific protein.

The modified RNA shows properties of its genetic composition and its past history. The glial metabolism is "locked" to that of its neurone and a feed-back relationship allows the neurone to make its energy demands on the glia. These changes do not affect the germ cells, so each new individual inherits only the genetic, unchanged RNA.

If further experimentation establishes this theory, there will be a physical basis for learning in the change in amount and kind of RNA and a limitation upon types of learning, determined by the original composition of the inherited RNA.

experimental semiconductor device FABRICATION

ELECTRONICS MATERIEL SCIENCES LABORATORY (AFCRL)

The semiconductor device field has long passed the point where new device concepts can be experimentally worked out with a pair of tungsten points, a micromanipulator and a small furnace for making alloy junctions. New High-frequency, low-power devices depend on extremely precise control of junction depth by impurity diffusion with area dimensions carefully maintained by photo-resist masks and etching techniques.

To fabricate experimental models of semiconductor devices, integrated devices or microminiaturized circuits, the research laboratory must not only build or purchase special furnaces and other equipments but, equally important, must (often through trial and error) gain a body of experience in the new largely uncharted art. AFCRL in recent months has obtained the capability in both trained personnel

and equipment for making experimental semiconductor devices of the most advanced and complex types.

Solid state physicists at AFCRL, for example, have fabricated experimental silicon planar transistors with Betas of over 150 at low frequencies with high frequency cutoffs at above 150 megacycles. This necessitated the design and construction of diffusion furnaces with flat temperature zones, and the perfection of the many minute but critical details connected with their optimum performance. Diffusion of impurities have been regulated to one-half micron variation in depth. This means that a p-n junction can be formed by diffusion to within plus or minus a half micron from a predetermined depth in the silicon. For example, the emitter-base junction is regularly placed within one micron of the collector-base junction without electrical shorting of the device.

The planar geometry of the device is obtained by etching selected patterns (in an SiO_2 surface layer) which were originally printed on the oxidized silicon surface by a photographic process that employs an acid resisting emulsion, i.e., the emulsion becomes acid resistant where it has been exposed to light. The final oxide pattern then serves as a mask for p or n type gaseous diffusion wherein adjacent diffused areas are routinely placed within 25 microns of each other. To make the planar transistor, four different photographic configurations are used with registration between masks as precise as one-half micron. The entire active area of such a device occupies only about 1/10 the cross sectional area of the wire of a common paper clip.

This particular device was selected for investigation because it would be a good testing vehicle for the above mentioned techniques and because of its inherent surface passivation due to the oxide masking. Leakage current is 10^{-9} amps or less because of the passivation in current devices; although voltage breakdown characteristics are inferior to non-passivated devices. Efforts are under way at AFCRL to regain the voltage characteristics while maintaining the other desirable features of the planar structure.

A high frequency unipolar device having channel widths of 6 microns is currently being developed. This will require at least an order of magnitude improvement in the photolithography over that required for the planar transistors.

metastable states in CADMIUM SULFIDE

DR. LEE DEVOL, Solid State Physics Research Laboratory (ARL)

A number of new scientific discoveries made with respect to cadmium sulfide by scientists of the Aeronautical Research Laboratories were briefly mentioned in an article entitled "A Flexible Solar Battery" in the 9 February 1962 issue of the OAR Research Review. This article will present a greatly simplified description of phenomena associated with the presence of metastable states in cadmium sulfide which were first reported almost four years ago but are still being investigated because of their theoretical significance and potential practicable value

Semiconductors, such as cadmium sulfide, differ from metals in the manner in which they conduct electricity. In a metal, all the valence electrons are free to move about, and so to contribute to the conductivity. In a semiconductor the electrons can fall into two classes: (1) those which are attached at fixed places in the crystal lattice and are said to be in the "valence band", and (2) those which are free of such attachment and are said to be in the "conduction band". This is illustrated in Figure 1, which is a simplified energy band model of a cadmium sulfide crystal at 77°K. The energy of the electrons, in electron volts (ev), is plotted in the vertical direction. Representation of an electron by a point on the diagram indicates its energy, but has nothing to do with its position in the crystal.

In a pure crystal, with a perfect lattice structure, at a temperature of absolute zero, all electrons are in the valence band and the crystal is a perfect insulator, providing no light energy or energy of some other form is supplied. At higher temperatures a varying number of "free" electrons are in the conduction band as a result of thermal agitation. The energy of the least energetic electron in the conduction band is greater than that of the most energetic electron in the valence band by at least a minimum amount called the "band gap" energy, which is characteristic of the material; for cadmium sulfide the "band gap" energy is about 2.54 ev at 77°K. In a pure crystal with a perfect lattice structure, no electron can remain

at equilibrium in the band gap region. However, no such crystal exists, and structural flaws or impurities in semiconductor crystals can provide what are called "electron trapping centers", where an electron can be caught and remain within the band gap. In Figure 1, two sets of such trapping centers are indicated at which levels an electron would have an energy either 0.75 ev above the valence band, or 0.14 ev below the conduction band.

Just as free electrons can exist in the conduction band, "holes" can be present in the valence band. These holes can conduct electricity, just as electrons in the conduction band can. Holes can also be caught and held in "hole trapping centers" within the band gap.

Some of the most important properties of semiconductor crystals, both for the purpose of understanding their true nature, and for the development of practical applications, depend on trapping centers, and on metastable states of the crystals made possible by the trapping and release of electrons or holes by these centers.

Two rather remarkable manifestations of this trapping were first reported by Warshauer and Reynolds. They observed that, at a sufficiently low temperature, some cadmium sulfide crystals, when exposed to light of 1.79 ev energy and then subjected to a light mechanical tap in the dark, emitted a flash of green light. After exposure, but before tapping, the crystal may be described as being in an activated state. The color emitted is characteristic of the "edge emission" of this material, so called because the energy is close to the 2.54 ev energy difference between the upper limit, or edge, of the valence band and the lower edge of the conduction band, as indicated in Fig 1. Of the order of 1000 flashes could be obtained by repeated tappings without reexposure to light, or reirradiation. The wave length of the emitted green light is about 0.51 micron, while the 1.79 ev light which can activate the crystal is red and has a wave length of about 0.69 micron. The crystals which display this phenomenon have been referred to as "tap effect" crystals.

The other remarkable manifestation of the trapping is that, when in the activated state, after irradiation, the electrical conductivity of these crystals may be greater than 10^9 (a thousand million) times the conductivity before irradiation. In the absence of tapping or some other triggering action, the high conductivity will remain almost indefinitely if the low temperature is maintained.

Triggering can be accomplished not only by tapping but also by (1) irradiation with infrared light of quite low energy, (2) mounting

electrodes of certain metals on the crystal and applying a voltage to the electrodes, or (3) simply raising the temperature to about 200° K. The return from the activated to the normal state consists in the return of electrons to the valence band, and is accompained by the green "edge emission".

The mechanism proposed for this phenomenon can be explained by means of the energy band model shown in Figure 1. It is assumed

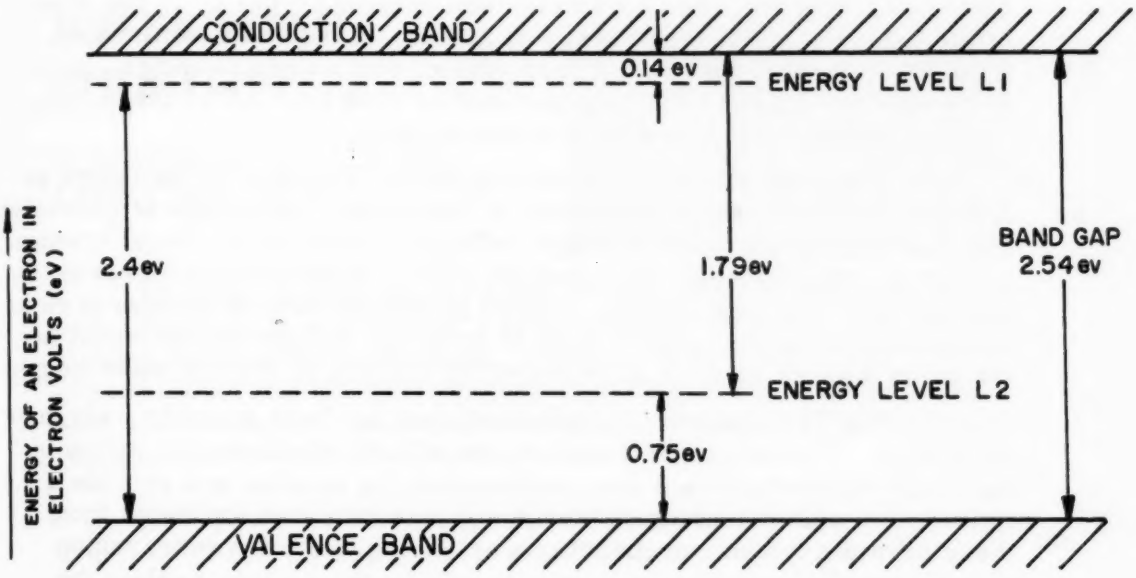


Fig. 1 ENERGY BAND MODEL FOR CADMIUM SULFIDE AT 77°K.

that electrons can be trapped at an energy level L1, about 0.14 ev below the conduction band, and that holes can be trapped at a level L2, approximately 0.75 ev above the valence band. The activation consists in the "raising" of an electron from level L2 to the conduction band, the energy required being the 1.79 ev difference between these two levels. This leaves a hole trapped in the L2 trapping level. Enough of the electrons that are raised to the conduction band drop back to level L1 to fill that level; the rest are left in the conduction band where they are free to move and can conduct electricity, just as the valence electrons in a metal. Thus, in the activated crystal, a number of electrons are resident in the conduction band, a number are trapped at the L1 level,

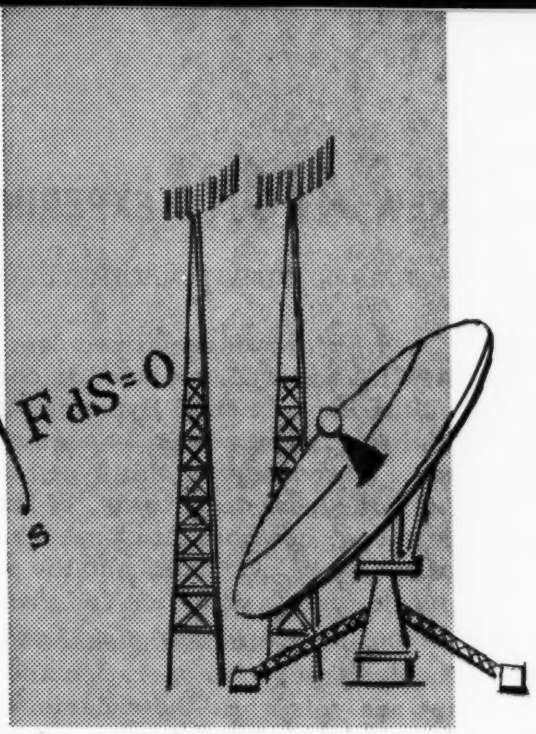
and a number of holes are trapped at the L2 level. When triggering is accomplished by irradiation, the incident radiation must have an energy at least equal to the 0.75 ev between the valence band and level L2. This radiation, which is in the near infrared, with a wave length of 1.62 microns, raises an electron from the valence band to level L2, releasing a trapped hole from this level to the valence band. This hole is then free to move about, and so to find and combine with an electron in level L1. In combining, the electron falls back to the valence band with emission of the characteristic green light. Another electron then drops from the conduction band into the vacancy left in level L1, keeping that level full. The emission by an electron dropping from L1 to the edge of the valence band has an energy of 2.4 ev. In addition, emission from other levels close to the band edges, which are not shown, gives other spectral lines in the neighborhood of 2.54 ev. All of these lines combine to form the green edge emission band.

The light emission on tapping the crystal may be explained as follows. When pressure is applied to the crystal, a voltage is generated which is called the "piezoelectric voltage". Tapping a crystal creates an almost instantaneous compression wave. If the pressure created is high enough, the piezoelectric voltage generated may be enough to raise an electron from the valence band to level L2, triggering emission in the same manner as does infrared radiation of 1.62 micron wave length.

The "piezoelectric" hypothesis has not been quantitatively substantiated. Planned experiments on the effects of ultrasonic waves in cadmium sulfide crystals may substantiate its validity and provide a quantitative understanding of mechanically stimulated emission from these crystals. Also, preparations are being made for research on the electrical properties of cadmium sulfide, which may explain the phenomena on which both the optical emission and the stored conductivity displayed by these "tap effect" crystals depend.

The practically permanent nature of the stored conductivity suggests application to a simple and extremely sensitive low-noise detector of infrared radiation; the emission of visible light as a result of exposure to infrared radiation points toward infrared imaging for military applications. However, characteristically, the real importance of the results of this basic research lies in the increase in scientific knowledge, in this case demonstrating the feasibility of storing a very large number of electrons in the conduction band and subsequently releasing them at will. A more complete understanding of the phenomena involved may suggest even more dramatic and useful effects that may be possible with cadmium sulfide, or other crystals prepared under somewhat different conditions.

MATHEMATICS FOR ANTENNA DESIGN



ELECTROMAGNETIC RADIATION LABORATORY (AFCRL)

To those without appreciation for the optics and mathematics of the problem it would seem a simple matter to design the optimum antenna for a given application. It isn't. No one can claim that a given antenna has the best possible matching of radiation pattern, size and the easiest realizable electrical excitation. The mathematics are inordinately complex and elusive.

Real progress in finding optimum antenna configurations, however, was recently reported by an AFCRL contractor, the Stanford Research Institute. The report represents a great deal of exceedingly difficult and complex mathematical toil. By framing the problem in terms of smoothness of the aperture excitation functions and by use of the calculus of variations, a method of synthesis suitable for electronic computers was evolved. This attention to the essential physics of the problem has enabled workers to find the proper mathematical web which weighs closeness of fit against realizability and antenna size.

Optimum amplitude in phase functions are found by allowing the phase of the radiation pattern to be initially unspecified. The method brings the power of calculus of variation methods, good physical insight and electronic computers to bear on tough design problems. Results, although modest thus far, appear to be sufficiently general to solve antenna design problems heretofore worked out only by approximations.

NEW *AFCRL* EXPERIMENTAL DATA PROCESSOR

COMPUTER AND MATHEMATICAL SCIENCES LABORATORY AND DETECTION PHYSICS LABORATORY (AFCRL)

A new specialized data processor has been delivered to AFCRL and will be placed in operation in July. This device, known as the Experimental Dynamic Processor, is of a class of hybrid digital computers that is seeing increasing use in research laboratories. Processors of this type are designed for the statistical processing, on a real-time basis, of large volumes of data -- waveforms, patterns, components of speech and so on. Inputs usually consists of analog sensor data, and the primary output consists of statistical predictions, estimation and classification.

The EDP is distinguished by the fact that the operator can monitor the data reduction operation and can intervene and control the course of the analysis while the experiment is in progress. Such dynamic processors are of great value whenever the experimenter is not quite certain what he wants analyzed and therefore cannot specify a program in detail. The program, in a sense, can be constructed or refined during the analysis. Although large, general-purpose computers with their elite corps of expert programmers will always be needed for certain classes of problems -- problems dealing with numerical analysis, game playing and other operations involving precise symbol manipulation -- the general-purpose computer is no longer the dominant data tool in the well-equipped research laboratory. The dynamic concept permits the experimenter to become intimately involved in the processing operation.

Such computers are usually smaller and less expensive than the general-purpose machine. Their growing use results from improvements in reliability, economy of components and the ease with which they can be tailored to particular requirements. Equally important are improved user oriented programming languages for simplifying communication with the processor. Control of the analysis while it is in progress presupposes a display system for monitoring the output. For this purpose, the AFCRL processor uses a large color scope on which can be displayed various types of graphic data. Light pencil communication is used for on-line process monitoring, and a precision display is available for photographic recording of processed data.

Among the first work to be performed on the new processor will be the certain problems concerned with ballistic missile detection and with studies involving on-line, adaptive filter design techniques.

notice to our readers

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